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About Physics, Myself, and Ginzburgs

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If you are also an admirer of Vitaly Lazarevich Ginzburg, you will recognize the present title as a reference to his most recent book, "About Science, Myself, and Others" [1]. Hopefully, after reading this article, you will also recognize certain similarity in the style of writing. This is deliberate and meant to be a tribute—an acknowledgement that his tenets have been noticed, understood, and appreciated. It is also meant as a reassurance that his influence will continue to live long. The most striking aspect of that book, to me, is its openness—talking so directly and candidly about one's private thoughts and feelings. I could see no deliberate attempts to impress the reader. If you have also read "You are surely joking, Mr. Feynman," you couldn't but be stricken by the contrast. Don't let me be misunderstood—Feynman is another of my personal heroes all the same; genius may come in all kinds of personalities. And Feynman is certainly not an exception at all. Most autobiographies of great men, scientists or otherwise, that I have had a chance to read [Despite our names, Natasha and I are nor Russians—we do not even speak Russion, although both of us can read it.] left me in wonder why the author felt such strong need to prove that he was really smart—as if anyone doubted. Now, while not everyone can afford what befits Vitaly, his example is enticing. (Here I will not use Vitaly Lazarevich, which would be more proper but could sound awkward to non-Russian readers.) He makes one wish to be a more sincere person—as well as a better physicist. So, here is my offering, in his style—as candid as I can be. And the topic will be the great influence Vitaly had and has in my life as a physicist.

My first direct encounter with Vitaly's writing occurred exactly 35 years ago, in 1971. (Indeed I came across the Ginzburg–Landau theory even before, but only from secondary sources such as textbooks.) I was a freshman graduate student of physics at Belgrade University, in what then was Yugoslavia. The place was terribly remote in space from any center of science—and even more remote (at that time) by some other measures. Indeed I was in the dark and 'searching for my soul' as a physicist. I was unsure where to go; reading textbooks was one thing but choosing a physics problem to which one should devote many years of life was a different matter altogether.

So I browsed aimlessly through volumes of Phys. Rev. Lett., Phys. Rev., and the like, bewildered by thousands of problems attacked by various researchers. How did they choose the problem to work on; why did they choose that particular one; why was it important? (Several decades later, I have grown wiser. In most cases, the problem is actually not chosen because it is important but because it is doable—preferably easily. The typical scenario may go like this: we have a technique (apparatus,. . .) that is available and familiar; there is a sample that we can make, get or borrow, so let's go and

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measure—one can always contrive some motivation subsequently! But this I did not yet know as a graduate student.)

This all changed when I read Vitaly's famous article: "What problems in physics and astrophysics seem now to be especially important and interesting" published (in Russian) in Uspekhi Fizicheskih Nauk [2]. The journal itself was translated into English cover-to-cover, but this was not available to me at the time; the article itself was reprinted later in English as a stand-alone booklet [3]. It changed my life, to say it concisely. Imagine you were shipwrecked in a stormy ocean, lost and struggling seemingly forever in darkness and chaos, and then suddenly seeing a lighthouse—this is how it felt. It introduced order where there was only turmoil and confusion before. Here was someone I could trust saying loud and clear that some problems in physics are indeed much more important then the rest. What's more, he actually listed the key problems for everyone to know and choose from. He indeed admitted that there was some degree of subjectivism in his judgment, but the point was that this was *Ginzburg's* judgment.

To draw an analogy, one century ago, David Hilbert—arguably the greatest mathematician of his time—presented to the world his selection of the most important open problems in mathematics. Most of these have been solved by now; in the process, new techniques were developed and new fields opened; throughout the 20th century the Hilbert's Problems kept profoundly influencing many mathematicians. To me at least, "The Ginzburg's List" was the physics equivalent.

This little piece of Vitaly's scientific writing has been my beacon ever since. I have read it and reread it many times, and in all subsequent editions, the few latest ones with VL's personal dedication. Despite its ostensible simplicity of expression, to me it seems inexhaustible—each time I read it, I see something new, and it triggers new thoughts and ideas.

Now, some problems from his list indeed seemed to me more appealing then the others. (For example, for unclear reasons, astrophysics that Vitaly loves so much leaves me indifferent. Perhaps it wouldn't if I had the chance to hear his lectures early enough in my development.) One of the very few problems I was fascinated the most, probably already in the first reading, was hightemperature superconductivity (HTS). (Another was X-ray lasers, but I dropped that one as undoable after wasting a year or so.) Again, it is hard to explain why; perhaps because I was fascinated by quantum mechanics (thanks to a good teacher) and this was a manifestly quantum phenomenon—and on a macroscopic scale at that. But I had no idea what could I do, or try, technically and concretely, that could be relevant to achieving or understanding HTS.

Few years later, I was working on my PhD thesis, on symmetries of polymers and quasi-1D crystals. This seemed doable at Belgrade; there was some local strength in Group Theory both in physics and in mathematics community. (Natasha was doing her mathematics PhD thesis in Group Theory as well, so we could talk shop at home.) Soon I zoomed onto the Jahn-Teller effect (JTE) in quasi-1D conductors. This is a somewhat esoteric subject and may require a little explanation.

Generally speaking, JTE is a '0D' phenomenon—it occurs in molecules or small isolated atomic clusters. It does not happen in higher dimensions. (Cooperative JTE can, indeed, occur in say molecular crystals, but this does not invalidate the above statement—JTE

still originates in individual molecules, while weak inter-molecular coupling merely phase-locks the distortions. So you can call this a quasi-0D case.)

In 1D, linear vibronic coupling leads to the Peierls instability. This is a phenomenon similar to JTE in its origin, but is much weaker in the sense that it involves only a small fraction of electrons, of the order of $h\_/E_F$, where _ is some characteristic phonon frequency. The Peierls instability thus produces only a weak *logarithmic* instability (where $\_E \sim Q^2 \log Q$) in contrast to JTE which causes a strong *linear* instability (where $\_E \sim Q$). In truly 2D or 3D metals, there is neither JTE nor Peierls instability. Namely, in this case general *k*-vectors (with no nontrivial point group symmetry) grossly outnumber special (high-symmetry) *k*-vectors; the latter form a 'set of measure zero' and generally don't count for much at all. To say it more technically, irreducible representations of the relevant symmetry group (the crystallographic space group that leaves the *k*-vector invariant) are one dimensional for every general *k*-vector. So there is simply no band degeneracy—except at few irrelevant points. Again, one could object that vibronic instability may occur if there is extensive nesting of the Fermi surface—but this is not too different from saying that the dimensionality is effectively reduced. This is all good and well known. (At least to experts—some HTS researchers seem uninformed of these facts.)

What is less broadly understood is that there may be a real and nontrivial exception to the above in *quasi*-1D systems, such as polymers. In this case, it is possible that *every k* vector has nontrivial point group symmetry, and thus one can have *band* degeneracy (where an entire electron energy band is degenerate). Take as an example a single-wall, zig–zag (4,0) carbon nanotube. It has $L8_4/mcm$ line group symmetry, and every *k*-vector has the C_{8v} point group symmetry [4]. The latter group has some two-dimensional irreducible representations, and as a consequence, in this nanotube some electron bands are two-fold degenerate throughout the Brillouin zone [4]. This in principle opens a possibility for the *band JTE*. For this to occur in reality, apart from the band degeneracy it is necessary that the band is relatively flat and narrow and partially occupied. (However, if the band is too narrow, localization occurs and we are back to 0D.)
Not long thereafter, already in late seventies, I have even identified a candidate compound for the *band JTE*—a bizarre electron-deficient polymer, $(BeH_2)_n$. It has been a favorite of quantum chemists at that time (of Kbyte computers) because it only contains the lightest atoms. This compound can be doped with Li to shorten the chains and promote crystallizations; this could introduce carriers in the topmost, two-fold degenerate band. Thus, I predicted (somewhat shyly) that Li-doped $(BeH_2)_n$ could be metallic, should show strong electron–phonon coupling, and perhaps could be a high-temperature superconductor. At that time to me that meant something like 20 K.

Three decades later, I still haven't got the chance to satisfymy curiosity and convince myself that beryllium hydride is uninteresting. I did try more than once to get someone interested in funding and enabling the experiments. By now, I probably have acquired and even demonstrated all the necessary technical skills, but this is a hard sell—beryllium is very toxic, hydrogen and lithium very flammable. Yet I would still like to try—Vitaly's lure of HTS (and now room-temperature superconductivity, RTS) is like the Orpheus' lyre.

Twenty years ago, a twist of fate brought me into the world of real high-temperature superconductors, viz. cuprates. Interestingly enough, the search and the discovery itself were motivated by Karl Alex Mu¨ ller's thinking along similar lines. To this day, he kept believing that in cuprates JTE is operational and leads to formation of bipolarons that Bose-condense into the HTS state. But in all fairness I must say that this viewpoint does not seem to be popular with most mainstream theorists, who actually believe that electron–phonon coupling does not play a major role in cuprates—if any. I am personally not swayed one way or another yet—while I see clear signs of strong electron-phonon coupling, I am as yet unaware of a clear and definitive proof that this contributes significantly to HTS.

After a stunt in HTS spectroscopy at Stanford, I have settled as a HTS film grower, first at the Varian Research Center in Palo Alto, then at Oxxel in Bremen, Germany, and in the last few years at BNL. The method that I learned at Varian is shuttered molecular beam epitaxy (MBE), also known as atomic-layer-by-layer MBE. This is what I have been doing ever since. In Oxxel I built a new, more powerful MBE system, equipped with some state-of-the-art surface science tools. This paid off as my group was soon at the forefront, growing some of the most perfect HTS films, and in particular, stacking almost at will precise layers of different compounds, HTS and other related oxides such as manganites [5–8]. The machine has in the meantime been acquired by and moved to BNL, and it is fully functional. We have already performed at BNL some 250 growth experiments, and mastered some new complex oxides (such as bismuthates), thus enlarging our repertoire. Bear with me for a little—the only reason I am telling this is because it prepares the background for 'my Ginzburg story', as will become clear shortly. HTS research has brought me at many places and many conferences and at several of these I met Vitaly in person. To say that I was greatly impressed would be a gross understatement. To me, he was a living legend, grander than life. Nevertheless, our discussions and exchanges were not just monologues. What I know, I know; I am not swayed easily, even by the greatest authority. So we actually clashed on many details, and I held my own. (Let's agree with Natasha that I can be stubborn.) Of course, I would not dare debate theory with Vitaly, but HTS experiments I have been following quite thoroughly and simply I keep more experimental information in my head. Thus, if I felt that some or other of his statements contradicted the experimental facts known to me, I boldly questioned or challenged it. Again, this detail is important for the story I wish to tell. The pinnacle of our polemics occurred in the summer of 2003, when I visited Lebedev Institute and gave a talk at the Ginzburg seminar. I tuned the talk to 45_. Actually it lasted for 2 h, because of a vast number of questions and comments—I was interrupted at every point. Needles to say, the main culprit was Vitaly. He questioned and challenged just about every statement I made. I fought back, well I believe—I was entirely on my terrain. Note that this polemics was not held in private but in public—in presence of well over 50 people, the lecture hall was full. Certainly I was afraid of his possible reaction, but I got carried away with the argument. Actually, we were both shouting much of the time; he has a strong and commanding voice, and I can be loud as well, in particular when there is no microphone. Now, had this happened in US (or even more so, in Germany—I can't tell about other countries) I would have been blacklisted for life. (I did make a mistake of engaging in scientific disputes in the first year or two of my life in US, and I still feel the consequences.) However, Vitaly was not offended at all,

but rather thrilled—like a true sportsman who enjoys a good fight. He does not seem to care who is right and who wrong, but rather wishes to learn the truth. It is very hard to comprehend how rare this virtue is today.

After and despite this 'incident,' our friendship rather increased and extended to families. Natasha and Marijeta, my younger daughter who was spending a year in Moscow on a Fulbright Fellowship, visited Vitaly and Nina (Ivanovna) Ginzburg in their beautiful apartment in Moscow. Marijeta, who is a scholar in Russian literature, was immensely impressed by their huge library, both quantity and quality, as well as by their actual knowledge, understanding, and original thinking, which extended to other arts, including modern. And then there was their fascinating life story, and love story, which is rather unique. Nina survived a year in the dreadful Lubyanka prison, and was then exiled to a village near Gorky for eight years, Vitaly traveling back and forth. In 1949, Nina was a passenger on a boat that capsized in the middle of Volga in (Russian) winter, drowning all but 13 out of some 250 passengers; she was able to swim to safety. Her strength, intellect, energy, and optimism are striking;

Vitaly has found his match. Their relation, so much full of love and caring after 60 years of marriage, is hearth-warming. Someone with a literary talent should write a book, or a screenplay, about this couple.

The October of 2003 brought us all a great joy, when the Nobel prizes in physics were announced. I happened to admire, know well, and even be on friendly terms with all three laureates—Vitaly, Alexei Abrikosov, and Tony Legget. I was somewhat saddened by the fact that another friend and a great physicist, Lev Gor'kov, could not be included this time. Many (including Vitaly, who said as much explicitly and in public) felt that Lev has deserved the honor. Hopefully, this omission will be rectified sometime in the future.

Then, the real shock hit a little later, one night in early November of 2003. The phone rang in the middle of the night—perhaps 3 or 4 am. It was Vitaly, calling from Moscow. Without much overture he asked me whether I would wish to join him in Stockholm, as his guest. (Each Laureate can invite a few guests to the award ceremony, the royal banquet, and almost all other happenings but one—the private reception with the King and the Queen.) It is hard to describe my feelings at the moment—I guess I would not have been more overjoyed had I been the laureate myself. I was struggling with words to say, yes, indeed, it is the greatest honor, and I have not deserved it.

So we went to Stockholm. It was one of the happiest and most memorable events in my life, and Natasha feels much the same. There would be so much to tell about all that we have seen, and the people we met, but this is not the time and place. Let me stick to my subject, which is Vitaly, and what he had to say to me.

Of course, I was much puzzled, and I still am, why he had chosen me. I was sure that he knew very well, and was closer to, many physicists much better than me. Russia did not lack those, and many were actually his former students or collaborators. (Despite our names, Natasha and I are not Russians –we do not even speak Russion, although both of us can read it.)

Our reunion with Vitaly and Nina in Stokholm was very warm—they are simply wonderful people and we love them dearly. Actually, traveling from three sides of the world, we gathered first inside the Nobel Foundation Museum in Stockholm. Figure 1 memorizes one bizarre moment from that event: the tradition is that each Laureate signs on the back of one of the chairs there. But Vitaly has a great sense of humor and doesn't mind being funny.

Figure 1 Vitaly Ginzburg signs his name on the back of a chair in the Nobel Foundation museum; Nina Ginzburg is watching with clear amusement.

Past that we spent most of the week together. This included some quite private moments like going to a museum or shopping, but there were a lot of official events, essentially one or more every day. Indeed Vitaly was besieged by reporters; Fig. 2 was recorded during one of his press conferences. He was beaming and shining, throwing one-liners in English, of which (he complains) he does not have sufficient command. (He is renowned for his eloquence and orator skills in Russian.) One that I remember was the following. A reporter asked him: "Professor Ginzburg, you won the Nobel Prize. What was your particular secret?" to which Vitaly answered without a second of pause:

"To live long enough!" (Indeed, if you are reading this, and you live long *enough*, you will get it too.) His mind, at 87, was remarkably fast.

We were also immensely impressed by his energy—he does not seem to ever grow tired, even though he had some problems with his legs and was using a walking stick much of the time. He found time and energy to socialize with Swedish students, who threw a mock-up award ceremony initiating Vitaly into The Order of the Frog. He played his part perfectly and without reluctance; he gave an ex-prompt speech that surpassed his hosts in wit and humor. You can see him displaying his Frog Order in Fig. 3. Thanks to his walking stick, I guess, the young hosts spared him the request to hop around like a frog, which they did impose on few other new Laureates.

Figure 2 Vitaly at a press conference in Stockholm.

Indeed, there were also several quite serious events with a strict protocol, such as the main Award ceremony, and the

Figure 3 Vitaly showing his newly acquired Order of the Frog, bestowed upon him by the students of Stockholm University in a mock-up ceremony.

subsequent royal banquet. As the senior Physics Laureate, Vitaly was seated next to the Queen, and Nina next to the King. Neither Vitaly nor Nina appeared intimidated by the royalty and the decorum. Vitaly behaved as if he was born in the frock (tail coat). The four of us are shown in Fig. 4, posing in our most formal, just after award ceremony and before the banquet.

But after few days of ceremonies, Vitaly seemed to have had enough of reporters and the like, and suggested one afternoon that we 'hide' in their apartment in the luxurious Grand Hotel in Stockholm, and have just a private dinner, using room service. So he ordered pizza for all four, skipping other and definitely more attractive culinary alternatives. But Vitaly wanted to talk physics—which we did most of the time anyway, whenever there was a chance. Indeed, this time the talk drifted to HTS and RTS, and atomic layer engineering, and we talked much and animatedly about that. To an outsider, it must have looked as if we were quarrelling, but not just Natasha but also Nina seemed at ease and accustomed to such misbehavior. Figure 5 commemorates this event. An observant reader may have noticed a letter G on the T-shirt Vitaly has under his shirt. This stands for Geballe (the author of a wonderful article in this same volume). The full inscription is the Stanford KGB group—a student's joke from the time when Professors Kapitulnik, Geballe and Beasley worked together on HTS. Vitaly got it as a gift when he visited Stanford, and was wearing it in Stockholm. A remarkable sense of humor, since he has never been enamored with the real KGB, and indeed neither was Nina who experienced their hospitality for a year. At some point, I have invited Vitaly to visit Brookhaven. He replied that he is old and will not travel abroad again except for one occasion—to Stockholm as *my* guest. This remark was not just a surprise—it was a shock, him being so far off the mark. Ever since my first grade in elementary school, I have not suffered from inferiority complex. But on the other hand I am also well aware of my limitations and in particular of the fact that in physics I have accomplished next to nothing—a few decent papers, perhaps one or two cute ideas, and just much hard work in the lab building equipment, synthesizing, and measuring. So his model was, atypically, off by few orders of magnitude. I was rather embarrassed, in particular since he repeated this later in presence of other physicists, who knew better having read my papers (or even worse, not having read them at all). So I needed an explanation. I questioned whether he became uncritical (as it happens so frequently with even the greatest minds, regrettably), or was he just trying to flatter me? Neither model made sense. Vitaly was clearly as sharp as a needle, in physics and outside, and actually piercingly critical of anything and everything. And he flattered no one, royalty included; in particular, he had zero reasons to flatter me. I should say that the reverse was also not true, i.e., I never flattered him deliberately. (This is not in my nature in general.) While I do admire Vitaly as a scientist, a thinker, and a public person, and respect his opinion in

every matter, this is true only insofar that I don't think it contradicts some experimental fact. At this point I argue with him, and even raise my voice. I am sure he could find a more flattering company.

Figure 4 Ivan Bozovic, Nina Ginzburg, Natasha Bozovic, and Vitaly Ginzburg, immediately after the main award ceremony.

After some time, I have developed a model to explain this—I needed it in order not to feel like an impostor there. Simply, Vitaly at this point in life is a Teacher, and he wishes to pass the torch to a student. One of his unfulfilled dreams, and a major one at that, is RTS. (Note that RTS is ranked as number two problem in the latest version of Ginzburg's List.) While we do not know the mechanism of HTS, he thinks that phonons could be responsible—but that phonon pairing is unlikely to ever lead to RTS. Thus a different mechanism may be needed, and the one close to his heart must be the Ginzburg model—a superlattice in which metallic and insulating layers alternate on an atomic scale, and electrons are paired by exchanging excitons [9]. While excitons are unstable in metals, they naturally can exist in the insulators, and this special geometry may allow for a peculiar proximity effect, the result of which could be excitonic superconductivity. Theoretically, this could have a high T_c even within a weak-coupling regime.[2] Now, if this is Vitaly's great wish, and I am convinced that it is, the things get a little clearer. Once atomic-layer engineering is involved, I am not such an illogical choice; this has been my bread and butter for a while. And he knows I have interest in, and a well-funded program, to work on atomic-layer engineering of cuprates. (Not very many groups do at the moment, although there are several excellent scientists out there capable of first-class work. They have been diverted to other problems such as ferroelectrics and multi-ferroics, following the funding trends, which I find regrettable.)

So, I think Vitaly wanted to impress upon me the task of carrying this research on and testing his model, which he believes has promise. And his mentioning the Nobel prize was not out of tune with his list of the most important open problems in physics. He of

[2] See also a related article in this volume by W. A. Little, who was actually the first to propose an excitonic superconductor, although in a different (quasi-1D) geometry.

course did not mean that I should get one for what I have done so far; what he meant is that I—or anyone else for that matter—could and should get it provided we (a) focus on synthesis of atomically perfect metal-excitonic insulator superlattices, and (b) discover in one of these RTS! This, of course, is easier to believe.

Figure 5 I. Bozovic and V. L. Ginzburg, interrupted in discussing physics after a room-service pizza dinner in Ginzburg's apartment in the Grand Hotel in Stockholm. Vitaly is showing his Stanford-KGB T-shirt.

It is also clear that this is a very risky proposition. It is utterly possible that one would vast one's entire life trying and not finding anything. And perhaps Vitaly felt that I just do not happen to be made of the same material as Madame Curie, i.e., ready to dig for years through piles of pitchblende ore in search of something that could not even be there. Thus, perhaps, he felt the need to motivate me as strong as he could. In the end, I did get the message. The life is short, some problems are more important than the others, in physics and elsewhere, and in order to win at the lottery one should at least buy a ticket. I will try my best; I wish and hope that Vitaly will be around to share the agony and the ecstasy.

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